



Effects of Enzyme Treated Palm Kernel Expeller on Metabolizable Energy, Growth Performance, Villus Height and Digesta Viscosity in Broiler Chickens

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ABSTRACT: This study examined whether pre-treating palm kernel expeller (PKE) with exogenous enzyme would degrade its fiber content; thus improving its metabolizable energy (ME), growth performance, villus height and digesta viscosity in broiler chickens fed diets containing PKE. Our results showed that enzyme treatment decreased ($p < 0.05$) hemicellulose and cellulose contents of PKE by 26.26 and 32.62%, respectively; and improved true ME (TME) and its nitrogen corrected value (TME_n) by 38% and 33%, respectively, compared to the raw sample. Average daily gain (ADG), feed intake and feed conversion ratio (FCR) of chickens fed on different dietary treatments in the grower period were not significantly different. Although there was no difference in feed intake ($p > 0.05$) among treatment groups in the finisher period, ADG of chickens in the control (PKE-free diet) was higher ($p < 0.05$) than in all treatment groups fed either 20 or 30% PKE, irrespective of with or without enzyme treatment. However, ADG of birds fed with 20% PKE was higher than those fed with 30% PKE. The FCR of chickens in the control was the lowest (2.20) but not significantly different from those fed 20% PKE diets while birds in the 30% PKE diets recorded higher ($p > 0.05$) FCR. The intestinal villus height and crypt depth (duodenum, jejunum and ileum) were not different ($p > 0.05$) among treatments except for duodenal crypt depth. The villus height and crypt depth of birds in enzyme treated PKE diets were higher ($p < 0.05$) than those in the raw PKE groups. Viscosity of the intestinal digesta was not different ($p > 0.05$) among treatments. Results of this study suggest that exogenous enzyme is effective in hydrolyzing the fiber (hemicellulose and cellulose) component and improved the ME values of PKE, however, the above positive effects were not reflected in the growth performance in broiler chickens fed the enzyme treated PKE compared to those received raw PKE. The results suggest that PKE can be included up to 5% in the grower diet and 20% in the finisher diet without any significant negative effect on FCR in broiler chickens. (**Key Words:** Palm Kernel Expeller, True Metabolizable Energy, Enzyme, Broiler)

INTRODUCTION

The primary challenge of using agro-byproducts as feed ingredients for mono-gastric animals, such as poultry, is to release the nutrients bond to the fiber component of these materials. Palm kernel expeller (PKE), a byproduct of the palm oil industry, contains 13 to 20% fiber (Alimon, 2004) with 58 to 78% of the fiber is insoluble glucomannan (Daud

and Jarvis, 1992; Dusterhoft et al., 1992; Sundu and Dingle, 2003) thus making it resembles very much cellulose by being crystalline, hard and water insoluble (Knudsen, 1997; Sundu et al., 2006).

Supplementing exogenous enzymes into broiler diets containing PKE to enhance intake and growth performance has been previously reported (Yahya et al., 2000; Iyayi and Davies, 2005; Omojola and Adesehinwa, 2007; Sekoni et al., 2008) but results from the above studies were inconsistent, presumably due to different enzymes were used among studies and/or other influencing factors within the gastrointestinal tract (GIT) of the birds which may affect the activity of the supplemented enzymes. The latter includes i) differences in rate of passage resulting in variable retention times for the enzyme to act on the PKE in the GIT and ii) the core body temperature of chickens (41°C) (Tessier et al., 2003) is below the optimal temperature for enzymes activity (50 to 60°C) (Pardo and Forchassin, 1999; Siti Norita et al.,

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Submitted Aug. 31, 2012; Accepted Oct. 31, 2012; Revised Dec. 2, 2012

2010) and thus reducing their efficacy.

Saenphoom et al. (2011) recently reported that pre-treating PKE with exogenous enzyme degraded its cellulose and hemicelluloses components by 22.14 and 35.70%, respectively, and releasing multi-folds more reducing sugars than the raw PKE. The above data suggested large proportion of the indigestible polysaccharides in the PKE was hydrolyzed into soluble sugars, which now can be used by mono-gastric animals such as poultry. However, whether the reduced fiber content and the released nutrients based on chemical analysis can be absorbed and metabolized by the animals need to be tested. In this study, we examined whether pre-treating PKE with exogenous enzyme can improve its metabolizable energy value and growth performance, villus height and digesta viscosity of broiler chickens fed diets containing the enzyme treated PKE.

MATERIALS AND METHODS

Preparation of PKE samples

Raw PKE was obtained from a commercial kernel oil extraction mill in Klang, Selangor, Malaysia and ground to uniform size of about 2.5 mm before undergoing enzymatic treatment. The enzyme used for this study consisted mainly cellulase and mannanase. Approximately 500 g of PKE was placed in 2 L laboratory beaker in which water was added to achieve a moisture content of about 80% before adding the enzyme at 0.67% of the weight of PKE (Saenphoom et al., 2011). The PKE sample was incubated at 55°C in water bath for 18 h after which the samples were dried for 48 h at 60°C and stored at 4°C for later use. The above procedure was repeated until sufficient amount of enzyme treated PKE was obtained for the study.

True metabolizable energy (TME) assay

The TME bioassay was conducted according to the procedure of Sibbald (1975) modified by McNab and Blair (1988) and the experimental protocol of Sibbald (1989) was used for the measurement of endogenous energy losses (EEL). Thirty six (36) birds (Cobb 500) of 60 d old (approximately 2.9 kg), raised with commercial starter (CP 21.4%), grower (CP 18.7%) and finisher (17.0%) diets kept in individual metabolic cages were used for this study. Three feed ingredients consisted of corn (as reference), raw PKE and enzyme treated PKE (as previously described) were tested. Each of the above test ingredients was randomly assigned to a group of 9 birds with another group of 9 birds used for the estimation of endogenous nitrogen and energy losses (Bilgili et al., 1982).

Forty-eight hours prior to feeding the test ingredients, feed was withdrawn from all birds. During fasting, birds were fed with 100 ml glucose solution (600 g/L) at two equal doses of 50 ml to meet maintenance energy

requirement of the birds. The birds were fed 15 g of test ingredient using a stainless steel funnel and the fourth group continued to fast. Total excreta voided were collected at 24 h and 48 h after feeding, weighed, dried at 60°C and ground. Chemical compositions the test ingredients and excreta samples were determined.

Feeding trial

Treatment diets were formulated to meet nutrient requirements of poultry according to the NRC (1994). In the growth performance trial, all birds were fed with commercial starter feed for the first 11 days. A combination of three grower diets (0% raw PKE, 5% raw PKE and 5% enzyme treated PKE) and five finisher diets (0% raw PKE, 20% raw PKE, 20% enzyme treated PKE, 30% raw PKE and 30% enzyme treated PKE) giving a total of 9 dietary combinations were used as treatment diets in this study. The compositions of the dietary treatments are shown in Table 1.

Two hundred and twenty five (225) male day-old chicks (Cobb 500) purchased from a commercial breeder farm in Selangor, Malaysia were randomly allocated into the above mentioned nine treatment groups. Each treatment consisted of five replications and five birds per replicate (5 birds/cages) making up a total of 25 birds per treatment. The birds were reared from d 1 to 11 (11 days) using starter, d 12 to 21 (10 days) grower and d 22 to 41 (20 days) finisher feed in battery cages. All birds were vaccinated against Newcastle disease (ND) and Infectious Bursal disease (IBD) on d 7 and 14, respectively. Feed and clean drinking water were offered *ad libitum* to the birds. Feed intake (FI) was recorded daily and body weights (BW) weekly for estimations of the average daily gain (ADG) and feed conversion ratio (FCR) during the various growth periods.

At the end of the trial period, ten birds from each treatment were randomly sampled and slaughtered. Duodenum, jejunum and ileum of the small intestine were sampled for histological examination. Villus height and crypt depth were measured according to the method described by Bejo (1990). Digesta samples were collected from the ileum to determine their viscosity. Four digesta samples from each treatment combination were used to estimate digesta viscosity using the Rheometer system with 0.5 ml of each sample in the Rheometer (Model: HAAKE MARS, Modular advanced Rheometer system, Germany) for 10 min at 25°C. Digesta viscosity was presented in Pascal-seconds (Pa-s).

Proximate analysis

Samples of the diets, raw PKE, enzyme treated PKE and feces were analyzed for dry matter (DM), crude protein (CP), ash, ether extract (EE) (AOAC, 1990), neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid

Table 1. Compositions of the dietary treatments

Ingredients (%)	Grower diets		Finisher diets		
	0% raw PKE	5% raw PKE and 5% enzyme treated PKE	0% raw PKE	20% raw PKE and 20% enzyme treated PKE	30% raw PKE and 30% enzyme treated PKE
Corn	61.87	56.36	63.30	48.65	39.99
Soybean meal	30.13	29.16	22.46	18.79	16.88
Wheat bran	0	0	7.56	2.50	1.00
PKE	0	5.00	0	20.00	30.00
Palm oil	3.90	5.44	3.00	6.55	8.73
CaCO ₃	1.25	1.23	1.18	1.08	1.03
Dicalcium phosphate	1.80	1.79	1.45	1.46	1.45
Common salt	0.41	0.36	0.37	0.19	0.10
Vitamin premix ¹	0.06	0.06	0.06	0.06	0.06
Mineral premix ²	0.10	0.10	0.10	0.10	0.10
DL-methionine	0.24	0.24	0.22	0.25	0.26
L-lysine HCl	0.17	0.19	0.23	0.30	0.33
Choline	0.06	0.06	0.06	0.06	0.06
Antioxidant	0.01	0.01	0.01	0.01	0.01
Total	100	100	100	100	100
Calculated analyses					
ME (Mcal/kg)	3.08	3.08	2.99	2.99	2.99
CP (%)	19.00	19.00	16.92	16.92	16.92
Ca (%)	0.96	0.96	0.85	0.85	0.85
Available P (%)	0.48	0.48	0.42	0.42	0.42
Na (%)	0.19	0.19	0.18	0.18	0.18
Lysine (%)	1.10	1.10	0.99	0.99	0.99
Methionine (%)	0.53	0.54	0.49	0.52	0.52
Methionine+cystein (%)	0.84	0.84	0.77	0.77	0.77

¹ Vitamin premix supplied per ton of diet: vitamin A, 50,000 MIU; vitamin D₃, 10,000 MIU; vitamin E, 75,000; vitamin K₃, 20,000 g; vitamin B₁, 10,000 g; vitamin B₂, 30,000 g; vitamin B₆, 20,000 g; vitamin B₁₂, 0.100 g; calcium D-pantothenate, 60,000 g; nicotinic acid, 200,000 g; folic acid, 5,000 g; biotin, 235,000 mg.

² Mineral premix supplied per ton of diet: Se, 0.20 g; Fe, 80 g; Mg, 100 g; Zn, 80 g; Cu, 15 g; KCl, 4 g; MgO, 0.60 g; NaHCO₃.

detergent lignin (ADL) (Goering and Van Soest, 1970). Hemicellulose was calculated as NDF-ADF while cellulose as ADF-ADL. Gross energy was determined using bomb calorimeter (C2000 Basic, IKA@Werke, Germany).

Statistic analyses

The experimental data were subjected to analysis of variance procedures of SAS software (SAS, 1998). Differences among treatment means in TME were tested using t-test (independent group) (Steel and Torrie, 1980). Differences among combination treatment means in the feeding trial were tested using Duncan's New Multiple Range Test (DMRT) and orthogonal contrast for specific comparison. Orthogonal contrasts were performed when compared with control (raw PKE), types and levels of PKE. A significance level of $p < 0.05$ was used to differentiate between means.

RESULTS AND DISCUSSION

Chemical composition of PKE

Chemical compositions of enzyme treated and raw PKE

are shown in Table 2. Crude protein content of the enzyme treated PKE (20.84%) was 3-percent unit higher than the raw PKE (17.85%). Enzyme treatment decreased NDF and ADF contents by 18.59 and 12.92% ($p < 0.05$), respectively, resulting in hemicellulose content to decrease from 33.78 to 24.91% and cellulose content from 32.80 to 22.10%. The exogenous enzyme used in this study thus effectively

Table 2. Chemical compositions and gross energy of PKE with and without enzyme treatments (values as % of DM)

Item	Treatment		SEM
	Raw PKE	Enzyme treated PKE	
Crude protein (%)	17.85 ^b	20.84 ^a	0.37
Ether extract (%)	7.41	7.28	0.83
Ash (%)	5.24	5.51	0.90
NDF (%)	79.28 ^a	64.54 ^b	1.82
ADF (%)	45.51 ^a	39.63 ^b	0.98
ADL (%)	12.70	17.53	1.66
Gross energy (MJ/kg)	20.35	20.52	0.36

^{a,b} Values within the same row with different superscripts differed significantly ($p < 0.05$).

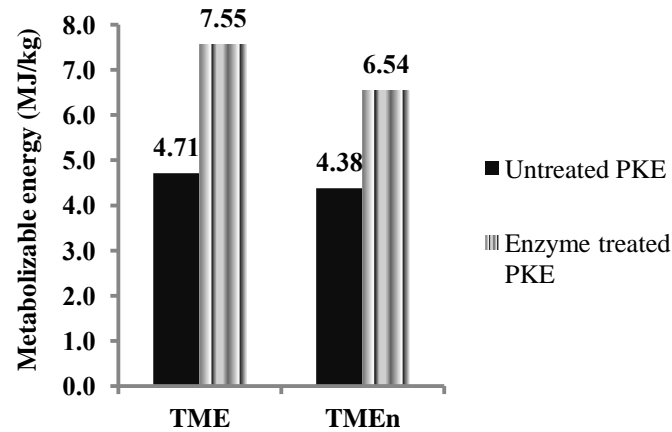


Figure 1. True metabolizable energy (TME) and nitrogen corrected TME (TME_n) of raw and enzyme treated PKE.

hydrolyzed complex hemicellulose and cellulose and reduced their contents by 26.26% and 32.62%, respectively, compared to the raw PKE. The above results reaffirmed our previous study (Saenphoom et al., 2011) which reported that pre-treating PKE with exogenous enzyme reduced hemicellulose and celluloses components by 26.26 and 32.62%, respectively. The significant reduction in hemicellulose content indicating the enzyme is effective in breaking down mannan-hemicellulose, the main component of the fiber in PKE (Daud and Jarvis, 1992; Yokomizo, 2004).

True metabolizable energy (TME) and nitrogen corrected TME (TME_n)

Enzyme treatment increased ($p < 0.05$) TME value of PKE by 60.3% (from 4.71 to 7.55 MJ/kg) and TME_n value by 49.3% (from 4.38 to 6.54 MJ/kg) (Figure 1). The above improvements were in agreement with the reduction of the fiber (cellulose and hemicelluloses) in the enzyme treated PKE compared to the raw PKE (Table 1). The above TME values were near to those previously reported in Malaysia (7.36 to 7.61 MJ TME/kg) by Yeong et al. (1983) and Chong et al. (1998), but lower than that reported (12.37 MJ TME/kg) by Muangkeow and Chinajariyawong (2009) in Thailand. Corn was used as the reference ingredient in this study, which was estimated to be 14.51 MJ TME/kg, approximately 5% lower than the value (15.36 MJ/kg) reported by Nadeem et al. (2005) and thus the TME values obtained in our study are reliable. The TME value of PKE (a high fiber agro-biomass) reported by Muangleow and Chinajariyawong (2009) seems to be unrealistically high taking into consideration that TME value of corn was estimated to range from only 14.51 (present study) to 15.36 (Nadeem et al., 2005).

Feeding trial

In the grower period (d 12 to 21), ADG, FI and FCR of

chickens fed PKE free diet and those fed 5% PKE (enzyme treated or raw PKE) were not significantly ($p > 0.05$) different (Table 2). The above results suggest that PKE can be included up to 5% in broiler-grower diet without any significant effect on ADG and FCR, averaged 50.51 g/bird and 1.55, respectively.

Although there was no difference in FI ($p > 0.05$) among treatment groups in the finisher period (d 22 to 41), ADG of chickens in the PKE-free control (70.49 g/d) was significantly higher ($p < 0.05$) than all treatments fed either 20 or 30% PKE, irrespective of with or without enzyme treatment. In general, feeding of PKE (enzyme treated or raw PKE) during the grower period did not affect subsequent ADG of chickens during the finisher period. However, ADG of birds fed with 30% PKE (T3, T5, T7 and T9) was lower than those fed with 20% PKE (T2, T4, T6 and T8) (55.16 vs 64.00 g/d). The FCR of chickens in the control PKE-free diet was the lowest (2.20) but was not significantly different from those fed 20% PKE diets (T2, T4, T6 and T8) while birds in the 30% PKE diets recorded higher ($p > 0.05$) FCR (Table 2). The above results thus suggested that to prevent any negative effect on ADG and FCR, the maximum inclusion rate of PKE (enzyme treated or raw PKE) is 20% in finisher broiler diet.

As for the overall feeding trial, FI and ADG of chickens in the PKE-free control diet were higher ($p < 0.05$) than the respective values containing PKE (irrespective of inclusion levels or enzyme treatments). Just as those in the finisher period, ADG of chickens fed 20% PKE diets (averaged 59.28 g/d) were higher ($p < 0.05$) than those in the 30% PKE diets (53.44 g/d). FCR of chickens in treatment 1 (PKE free; 2.02) were not significantly different with those fed 20% PKE (T2, T4, T6 and T8) but lower ($p < 0.05$) than those in the 30% PKE diets (T3, T5, T7 and T9). In general, enzyme treatment did not improve ADG or FCR of chickens fed the enzyme treated PKE (Table 3).

Majority of the previous research which aimed at

Table 3. Growth performance of chicken fed with different dietary combination treatments

Parameters	T1	T2	T3	T4	T5	T6	T7	T8	T9	SEM
Grower (10 days)										
ADG (g/bird)	51.36	50.20	50.44	49.52	49.72	51.08	50.24	51.36	50.64	0.25
Daily feed intake (g/bird)	79.47	76.93	77.84	77.73	77.69	78.23	76.84	79.26	78.54	0.27
FCR	1.55	1.54	1.54	1.57	1.56	1.53	1.53	1.55	1.55	0.01
Finisher (20 days)										
ADG (g/bird)	70.49 ^a	63.23 ^b	57.12 ^c	64.15 ^b	56.07 ^{cd}	62.89 ^b	52.26 ^d	65.73 ^b	55.20 ^{cd}	0.51
Daily feed intake (g/bird)	154.71	151.79	148.87	145.34	141.56	153.58	145.59	145.05	141.18	1.27
FCR	2.20 ^c	2.40 ^{bc}	2.61 ^{ab}	2.27 ^{bc}	2.53 ^{abc}	2.47 ^{bc}	2.83 ^a	2.21 ^c	2.56 ^{ab}	0.04
Overall										
ADG (g/bird)	63.98 ^a	58.38 ^b	54.44 ^c	59.17 ^b	53.91 ^c	58.73 ^b	51.76 ^c	60.83 ^{ab}	53.64 ^c	0.39
Daily feed intake (g/bird)	129.12 ^a	123.33 ^{bc}	121.51 ^{bc}	122.35 ^{bc}	119.83 ^c	124.70 ^b	119.47 ^c	122.67 ^{bc}	119.84 ^c	0.41
FCR	2.02 ^d	2.14 ^{bcd}	2.26 ^{ab}	2.07 ^{cd}	2.22 ^{abc}	2.17 ^{bcd}	2.36 ^a	2.02 ^d	2.24 ^{abc}	0.02
Initial weight (g/bird)	215.2	222.0	217.2	217.2	210.0	215.2	208.0	218.4	213.2	1.50
Final weight (g/bird)	2096.4 ^a	1986.2 ^{ab}	1866.4 ^{cd}	1956.8 ^{bc}	1794.8 ^d	1980.9 ^b	1760.9 ^d	2007.2 ^{ab}	1789.6 ^d	12.34
Mortality (%)	0.0	4.0	4.0	0.0	0.0	4.0	4.0	0.0	0.0	0.89

^{a,b,c} Values on the same row with different superscripts differ significantly ($p < 0.05$).

T1: Corn-soybean meal (SBM) diet without PKE (control), T2: 5% raw PKE in grower+20% raw PKE in finisher, T3: 5% raw PKE in grower+30% raw PKE in finisher, T4: 5% enzyme treated PKE in grower+20% enzyme treated PKE in finisher, T5: 5% enzyme treated PKE in grower+30% enzyme treated PKE in finisher, T6: 0% raw PKE in grower+20% raw PKE in finisher, T7: 0% raw PKE in grower+30% raw PKE in finisher, T8: 0% enzyme treated PKE in grower+20% enzyme treated PKE in finisher, T9: 0% enzyme treated PKE in grower+30% enzyme treated PKE in finisher.

improving the efficiency of PKE utilization in poultry were based on supplementing different exogenous enzymes into diets containing various levels of PKE. Available data seem to indicate an inconsistency in the results among studies. For example, Chong et al. (2003) reported that FI, ADG and FCR of chickens fed 20% PKE inclusion diet supplemented with enzyme were not significantly different with those of the PKE-free control diet but higher than diet with similar PKE inclusion rate without enzyme. Similarly, Esuga et al. (2008) showed that broiler chickens fed with 10 and 20% PKM (palm kernel meal) supplemented with enzyme had higher final weight and ADG than the birds in the control diet (maize based diets) and PKM without enzyme. On the other hand, Omojola and Adesehinwa (2007) and Soltan (2009) found supplementation of enzyme did not improve FI and animal performance in PKE inclusion diets compared to no enzyme PKE diet in broiler chickens. The inconsistent results among studies, as highlighted earlier, could be due to differences in the enzymes used and/or efficacy of the supplemented enzyme in the GIT of the birds (see Introduction). We do not know of any published data on the use of exogenous enzymes to pre-treat the PKE before feeding to chickens, as in the case of this study, except for a recent study (Lawal et al., 2010) which reported higher FI, weigh gain and nutrients digestibility in chickens fed PKE pre-treated with microbial enzyme extract than those fed PKE supplemented with the similar enzyme in the diets. However, the inclusion rate of PKE in their study was only 10% in the finisher diet which was much lower than the 20 and 30% inclusion rates used in our study. Although results among studies appeared to be

inconsistent, available data seem to agree that PKE (with or without enzyme supplementation) could be included up to about 20% in broiler diet without significantly affecting growth and feed conversion efficiency of the birds.

Villus height and digesta viscosity

Intestinal villi are the major site for nutrients absorption, thus higher villus height increases nutrients absorption due to enlarged surface area of the epithelium (Caspary, 1992), while crypt can be regarded as the villus factory and a large crypt indicates rapid tissue turnover (cell renewal) and high demand for new tissues (Yason et al., 1987). Reports on the effects on feeding PKE diets on intestinal villus height and crypt depth were inconsistent. Mustafa et al. (2002) reported that height and width of jejunum and ileum villus in ducks fed PKE inclusion diets were not significantly different. However, Rahim et al. (2007) reported that intestine villus height of broilers decreased with increasing levels of fermented PKE (0, 9, 18, 27 and 36%) in the diets while Zulkifli et al. (2009) found broiler chickens fed 25% PKM inclusion diet had higher and wider villus which the authors speculated that the higher fiber content of PKM could have stimulated development of the mucosa epithelial cells. Other researchers (Sklan et al., 2003; Jankowski et al., 2011) found that high CF content in the diet decreased villus height which possibly led to reduced feed intake.

Our results showed no differences ($p > 0.05$) in the intestinal (duodenum, jejunum and ileum) villus height of chickens among treatments (Table 3) while differences were detected ($p < 0.05$) among treatments for duodenum crypt depth but not those of the jejunum and ileum. The

Table 4. Villus height, crypt depth in small intestine and digesta viscosity of chicken fed with different dietary combination treatments

Parameter	T1	T2	T3	T4	T5	T6	T7	T8	T9	SEM
Villus height (μm)										
Duodenum	1,199.20	1,076.20	1,059.40	1,205.40	1,257.90	1,123.80	1,028.60	1,204.20	1,234.30	2.75
Jejunum	898.81	919.14	920.39	1,111.06	1,025.75	965.91	1043.39	1,053.80	943.82	2.11
Ileum	797.10	865.30	766.90	904.30	954.20	821.90	882.90	847.70	815.20	2.32
Crypt depth (μm)										
Duodenum	155.21 ^{ab}	130.24 ^{bc}	147.58 ^{abc}	134.31 ^{bc}	134.71 ^{bc}	142.25 ^{abc}	123.97 ^c	142.08 ^{abc}	166.69 ^a	0.25
Jejunum	136.85	122.99	137.68	151.61	129.51	139.82	135.18	149.12	136.96	0.33
Ileum	106.18	140.00	134.36	120.58	134.01	120.00	135.77	140.88	113.29	0.37
Digesta viscosity (Pa-s)	0.35	1.78	0.50	1.34	0.56	0.16	1.15	0.56	1.11	0.01

^{a,b,c} Values on the same row with different superscripts differ significantly ($p < 0.05$).

T1: Corn-soybean meal (SBM) diet without PKE (control), T2: 5% raw PKE in grower +20% raw PKE in finisher, T3: 5% raw PKE in grower +30% raw PKE in finisher, T4: 5% enzyme treated PKE in grower +20% enzyme treated PKE in finisher, T5: 5% enzyme treated PKE in grower +30% enzyme treated PKE in finisher, T6: 0% raw PKE in grower +20% raw PKE in finisher, T7: 0% raw PKE in grower +30% raw PKE in finisher, T8: 0% enzyme treated PKE in grower +20% enzyme treated PKE in finisher, T9: 0% enzyme treated PKE in grower +30% enzyme treated PKE in finisher.

duodenum crypt depth of birds fed with 30% enzyme treated PKE (T9) and control (T1) were significantly higher ($p < 0.05$) than all other PKE diets. However, comparison using orthogonal contrast analysis showed that villus height of duodenum and jejunum of bird fed with enzyme treated PKE was significantly higher ($p < 0.05$) than those in raw PKE. The mean values were 1,246.1 vs 1,044.0 μm for duodenum and 1,082.4 vs 942.5 μm for jejunum, respectively, for enzyme treated and raw PKE diets. In addition, mean ileum crypt depth of all birds fed with PKE was also higher ($p < 0.05$) than those of the PKE free control diet (129.9 vs 106.2 μm , respectively). The ratio of crypt depth to villus height in treatment diets was not different in each section of small intestine. Our results, in general, seem to suggest an increase in intestinal villus height and crypt depth in birds fed enzyme treated PKE. Since fiber content of the enzyme treated PKE was significantly reduced compared to the untreated one, our result thus not supporting the earlier speculation that higher villus height and/or crypt depth could be stimulated by the high fiber content in PKE diets. However, we do not have any reasons to explain for the effects.

Intestinal digesta viscosity is an indicator of nutrient digestibility and absorbability. Galactomannan and mannan are anti-nutritional factors present in feedstuffs including PKE and these compounds were reported to decrease nutrient digestibility and absorbability due to increased digesta viscosity of the gut content (Sundu and Dingle, 2003). The primary objective of the present study was to use enzyme to break down the insoluble non-starch polysaccharides of PKE into smaller molecule polymers which can then be made available to the chickens. Since 58 to 78% of the PKE fiber is insoluble glucomannan (Daud and Jarvis, 1992; Dusterhoft et al., 1992; Sundu and Dingle, 2003), large proportion of the end-products of enzymatic hydrolysis of its fiber would be galactomannan and mannan.

Digesta viscosity recorded in this study ranged from 0.35 to 1.78 Pa-s, but no significant differences ($p > 0.05$) were detected among treatments (Table 4). Our result is in agreement with that of Sundu and Dingle (2003) who reported that galactomannan of PKE which is hard, highly crystalline and with high mannose: galactose ratio and thus low water absorption capacity may not significantly increase its viscosity. Bedford and Schulze (1998) also reported that digesta viscosity had no effect on growth of chicken when this value is lower than 10 mPa-s. However, several studies reported enzyme supplementation decrease intestinal digesta viscosity in soybean meal (Saleh et al., 2003) and wheat-based (Gunal et al., 2004) diets in chickens. The discrepancy between the above two studies and those of Sundu and Dingle (2003) and the present study could be due to the feed ingredients used and thus their end-products from enzymatic hydrolysis.

CONCLUSIONS

Enzyme treatment effectively hydrolyzed the fiber components (cellulose and hemicelluloses) of PKE resulted in 38% increase in the TME value of the enzyme treated PKE compared to the raw PKE. As to why improvements in both reductions of fiber contents and TME of enzyme treated PKE were not reflected in the ADG and FCR of chickens fed enzyme treated PKE deserve further elucidations. However, we would like to offer the following explanation: because the fiber in PKE is mainly in the form of hemicelluloses-mannan (Daud and Jarvis, 1992; Dusterhoft et al., 1992; Sundu and Dingle, 2003) and thus large proportion of the sugars released during enzymatic treatment comprised of mannose. It has been reported that the absorption of mannose is much lower than glucose (Wilson and Vincent, 1955), particularly when glucose is present in the system. Therefore, although enzymatic

treatment of PKE released large amount of sugars, they are primarily mannose which are poorly absorbed and thus of little use to the chickens. Our results, in agreement with several previous studies, suggested that PKE can be included up 20% in broiler diets without adversely affecting growth and feed conversion efficiency.

ACKNOWLEDGEMENTS

This study was supported by Technofund of the Ministry of Agro-industry Malaysia. The authors would also like to thank FTR Bio-Agro Sdn. Bhd for providing the enzyme for this study.

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